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Numerical simulation on indoor thermal comfort of a new integrated rural heating system

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Abstract

INTRODUCTION: This paper presents a new rural energy usage mode based on biomass briquette boiler,which integrated cooking, water heating Kang, water heating bed, water heater into a system. The biomass briquette boiler produces hot water with high efficiency and low emission, the hot water can be sent directly into the heating system for room heating, sent into a special water heater for domestic hot water, and sent to water heating Kang or water heating bed for heating and ensure the comfortable of Kang's or bed's surface after reductions of temperature through mixing valve.
METHODS: In order to verify the feasibility and the comfort of thisnewsystem, Airpark software was used to simulate these two living rooms based on the measured data. Simulated the indoor temperature of new heating system room and traditional heating room, analyzed PMV and PPD of these two living rooms, and quantify their thermal comfort.
RESULTS: Simulation results show that the average PMV of traditional heating room is around -1.19, while the average PMV of new heating model room is -0.10; and the average PPD of traditional heating room is 39.8%, while the average PPD of the new heating model room is 13.47%.
CONCLUSIONS: It is obviously that the room with new heating system is more comfortable than the room with traditional heating system. In addition, comparing the economy analysis of these two heating systems, the new one has better economic performance through the life cycle. If this new system be widely used it will produce huge social and economic benefits.

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*Keywords:*Energy usage mode; Thermal comfort; Airpak simulation;Economical efficiency

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1. Introduction

With the development of society and farmers' living standards, the quality of living environment for farmers' requirement is increasing as well. The energy utilization rate of rural traditional Kang heating system is low, and that system has huge environmental pollution, big indoor temperature fluctuation and poor indoor thermal comfort[1]. In order to improve the living environment fundamentally, the most important things are changing the traditional heating method and using clean energy[2].

Based on this background, this paper proposed a new model of heating in rural areas. The main components of this system include biomass briquette boiler, water heater bed, heat radiator and the water-water heat exchanger. Hot water produced by the biomass briquette boiler can be sent directly into the heating system and water heating bed for room and bed heating instead of the traditional Kang, and the water-water heat exchanger is used for producing domestic hot water. This new system facilitates the lives of farmers and improves quality of farmers' life. The biomass briquette fuel which this system burned is made by strew pressing. Make full use of waste straw can make rural courtyard more tidy, greatly improve the rural village appearance[3]. At the same time, with the use of biomass briquette fuel, the use of fossil fuels can be reduced, which protect the ecological environment[4-6]. In addition, the cost for combusting biomass fuels less than coal, which has certain economy. New heating system integrating environmental protection, energy saving and economy, meets the requirement of building a new socialist countryside.

2. Operation of new rural heating system

According to the way of rural life, biomass briquette boiler is used three times every day, respectively in morning, noon and evening as conventional cooking time, worked as intermittent heating system. Winter morning, when farmer starts cooking, the biomass briquette boiler heats water, the hot water is been sent to water heating bed and heat radiator to heat the bed and indoor air. At this time the households' requirement for domestic hot water is low, so the water-water heat exchanger valve can be closed to priority ensure indoor thermal comfort, till indoor heat wealthy then open this valve to heat domestic hot water. According to the actual demand, when the user needs massive hot water, the water heating bed and heat radiator can be closed temporarily in order to speed up the heating rate of domestic hot water. During lunch cooking time, according to indoor temperature and room usage to adjust the switch of water heating bed, heat radiator and water-water heat exchanger. After the end of the evening cooking, biomass briquette stove fire, close the valve of water-water heat exchanger and parts of heat radiator according to the actual use in order to maintain the comfortable of water heating bed and bedroom as possible. The principle diagram of the system is shown in Fig. 1.

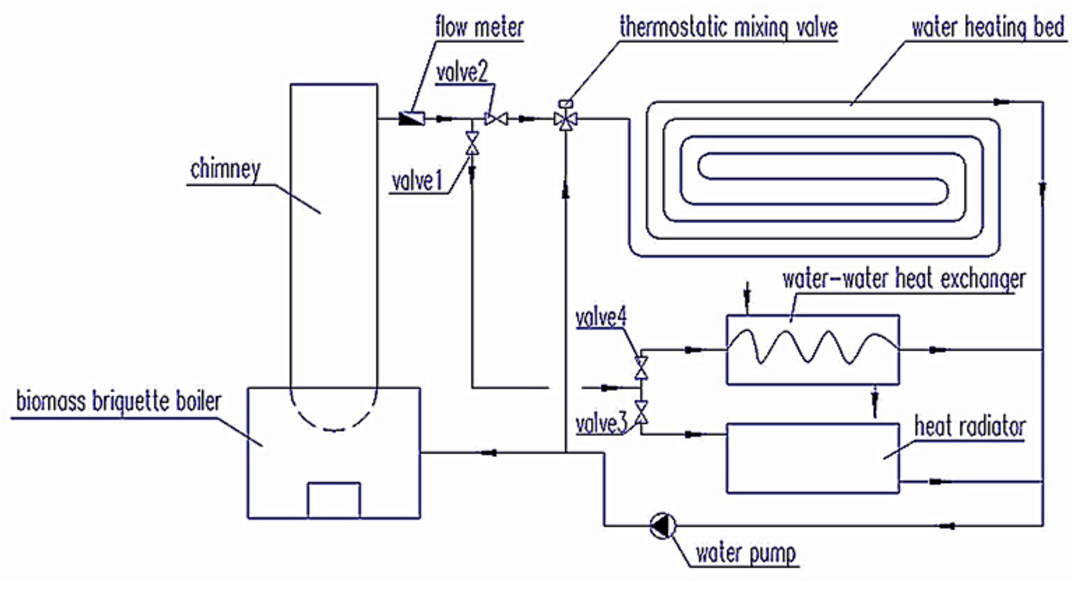


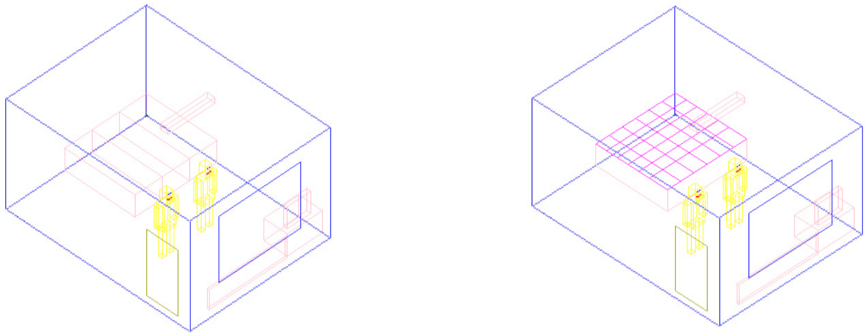
Fig. 1. *System principle diagram*.

3. Numerical simulation by Airpak

Used measured data as the simulation conditions, simulated thermal comfort of new heating system room and traditional Kang heating room respectively by Airpak simulation software. The main simulation objectives are: (1) Analysis indoor temperature distribution under steady state of new heating system room and traditional Kang heating system room respectively. (2) Simulated PMV and PPD of these two different heating system living rooms, and quantified their thermal comfort.

3.1. Set simulation rooms

Because farmer's mainly daily activity space is the living room with Kang or water heat bed, so the main stimulants are the rooms respectively with Kang and water heat bed. The size of these two rooms is 3.7m (long) * 2.8m (wide) x 3m (high), gate size is 2.0m * 0.8m, the southern window size is 2.1m (wide) x 2.1 (high), the size of traditional Kang and water heat bed is 2.0m * 1.8m * 0.6m. Room 1 is used traditional Kang heat system; room 2 is used the new model heating system. According to the relevant literatures and the practical application effect, the surface temperature of Kang is uneven, so we simplify divided the Kang into three parts as head 、 medium and tail. In order to form contrast the water heat bed also be divided into these 3 parts as Kang. Experiment data shown that the smallest room temperature change was during 13:00 to 14:00, and during this time the indoor temperature closed to average indoor temperature, so the data of this time was used as simulation design parameters. The experimental data were the measured surface temperature of heating source and non heating source in the rooms; boundary conditions of simulation were the actual measured surface temperature. In addition, according to the specific use of the room, set the analogue parameters as: two people with the surface temperature as 30℃; an electric light, which calorific value is 34W; a TV with 108W heating capacity. The physical models of the rooms are showed in Fig. 2:



a. Room 1 b. Room 2

Fig. 2. Physical models of the simulation rooms

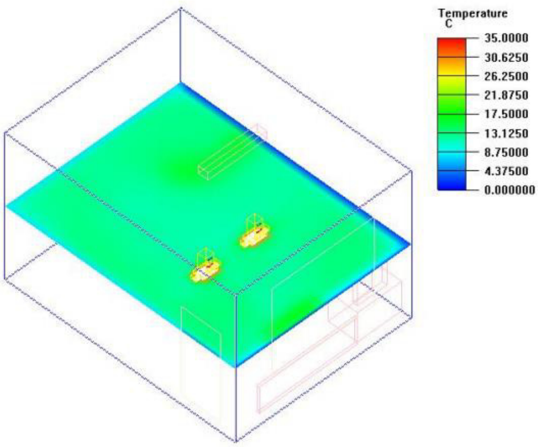
3.2. Grid division of the simulation rooms

This paper took the whole simulation room as computational domain to divided meshes, the maximum size of X axis is 0.3; The Max O-grid height is 0.001. In order to ensure the simulation results accurately reflect actual temperature distribution, divided more elaborate grid around the emission model, increased the number of calculation grid nodes, and set the priority level of simulation as highest.

4. Simulation results

4.1. Grid division of the simulation rooms

(1) The temperature distribution contours of two simulation rooms at the height of 1.5m got from Airpak software's analyzed are shown in Fig.3 and Fig.4.



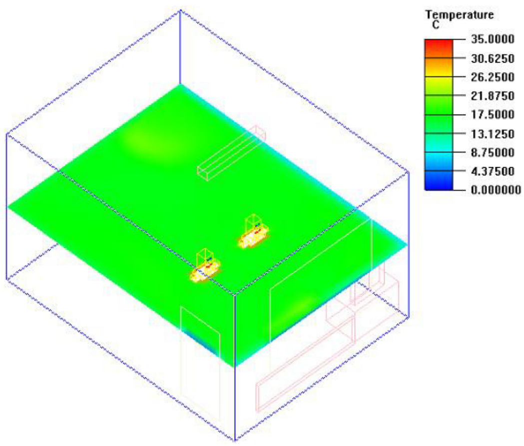
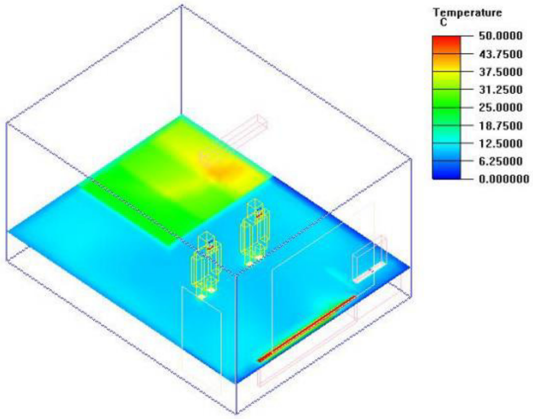


Fig. 3. Temperature contours at the height of 1.5m in room1 Fig.4. Temperature contours at the height of 1.5m in room2

From above diagrams we can tell that: the external walls' temperature of two simulation rooms is low. Affected by the walls radiant, the temperature of places near the wall is low, but the indoor temperature distribution of the whole room is uniform. Surface temperature of the simulation room with traditional Kang heating system at 1.5m height mainly concentrated around 11℃, while the surface temperature of the simulation room with new heating system at 1.5m height mainly concentrated around 16℃.

(2) The temperature distribution contours of two simulation rooms at the height of 0.7m got from Airpak software's analyzed are shown in Fig.5 and Fig.6.



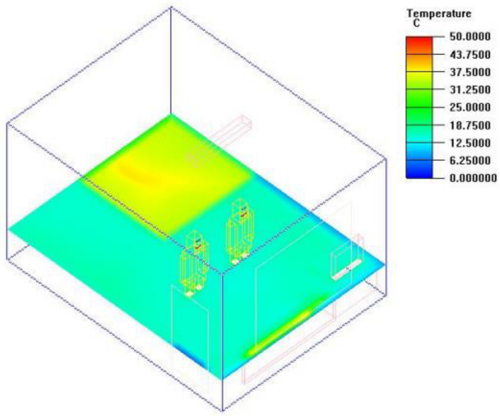


Fig. 5. Temperature contours at the height of 0.7m in room 1 Fig.6. Temperature contours at the height of 0.7 m in room 2

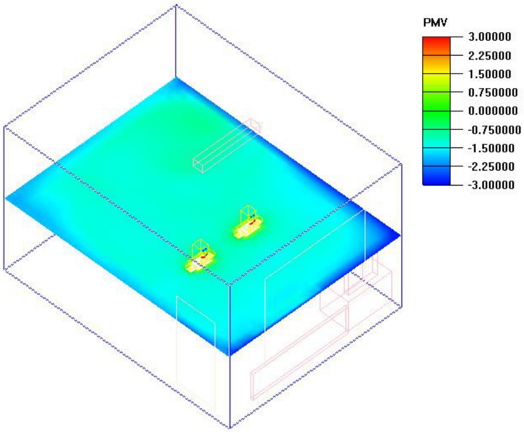
As can be seen from the above graphs, the temperature of Kang's head was mainly between 30℃ and 35℃, the temperature distribution of Kang's medium is mainly between 27℃ and 31℃, and the temperature distribution of Kang's tail was mainly from 24℃ to 27℃, the temperature distribution of Kang is not uniform; the indoor surface temperature at 0.7m height mainly forced on 9℃to 10℃. At the room with new heating system, the surface temperature distribution of water heating bed was more uniform, mainly concentrated between 35℃ and 37℃, the surface temperature was higher than traditional Kang and the temperature fluctuations was smaller; the indoor surface temperature at 0.7m height mainly forced on 15℃ to 16℃, around 6℃ higher than traditional Kang heating system room.

Therefore, the surface temperature of water heating bed is higher than Kang and the temperature distribution is more evenly. What's more, the average indoor temperature of the room with new heating system is higher than the room with traditional Kang and the temperature distributed is also more evenly. The new heating system has significant advantages for rural heating.

4.2. Thermal comfort analysis of two simulation rooms

The PMV and PPD of these two simulation living rooms with different heating system have been simulated respectively by using Airpak simulation software. The indoor parameters set as follows: all people in two rooms dressed as long underwear, long sweaters in the middle, regular clothes and long trousers at the outside, and wore stockings; human activity set as sedentary office status. Simulation results are as bellows:

(1) The PMV distribution contours of two simulation rooms at the height of 1.5m are shown in Fig.7 and Fig.8, the comparative analysis of PMV is shown in Table 1.



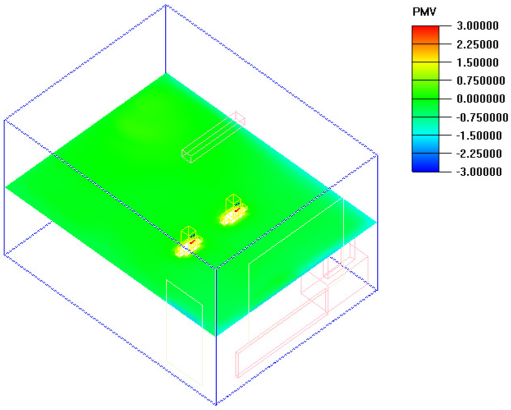


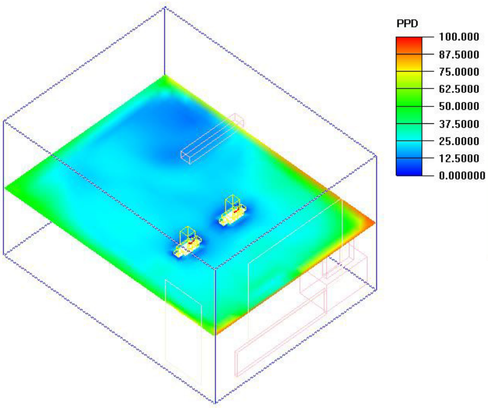
Fig. 7. PMV contours at 1.5m in room1Fig. 8. PMV contours at 1.5m in room2

Table 1. Comparative analysis of PMV

Room Number	Min	Max	Mean
Room 1	-2.46	2.56	-1.19
Room 2	-1.8	1.5	-0.10

The above charts show that the PMV values of simulation room with traditional Kang heating system at 1.5m from the ground are mainly concentrated from -2 to -0.75, the average value is about -1.19, the feeling is a little cold; while the PMV values of simulation room with new integrated rural heating system at 1.5m from the ground mainly between -0.75 and 0.75, the average value is -0.10, the feeling is more comfortable, the room with new heating system has better thermal comfortable than the room with traditional Kang heating system.

(2) The PPD distribution contours of two simulation rooms at the height of 1.5m are shown in Fig.9 and Fig. 10, the comparative analysis of PPD is shown in Table 2.



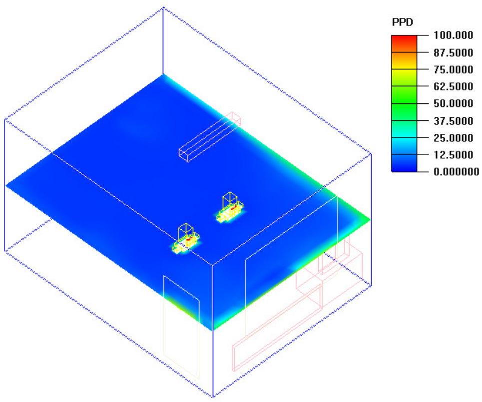


Fig. 9. PPD contours of 1.5m in room1Fig.10. PPD contours of 1.5m in room2

Table 2. Comparative analysis of PPD

Room Number	Min	Max	Mean
Room 1	5.00%	99.9%	39.8%

Room 2	5.00%	46.19%	13.47%

The above charts show that the PPD values of simulation room with traditional Kang heating system and the simulation room with new integrated rural heating system at 1.5m from the ground respectively focused on 25.6%-46.3% and 12.7%-20.4%; the average PPD value of simulation room with traditional Kang heating system is 39.8%, while the average PPD value of simulation room with new heating system is only 13.47%. Using this new heating system can effectively improves the comfortable degree of indoor environment.

5. Conclusion

This paper aiming at the shortcomings of traditional Kang's heating system in northern rural, put forward a new heating system which based on biomass briquette boiler, and used Airpark software to verify the feasibility of this system. Following conclusions can be drawn by numerical simulation: At the room with new heating system, the surface temperature distribution of water heating bed concentrated between 35℃ and 37℃, the surface temperature was higher than traditional Kang and the temperature fluctuations was smaller. Surface temperature of the simulation room with traditional Kang heating system at 1.5m height mainly concentrated around 11℃, while the surface temperature of the simulation room with the new heating system at 1.5m height was about 16℃. The average PMV value of the simulation room with traditional Kang heating system was about -1.19, while the average PMV value of the simulation room with new heating system was around -0.10. The average PPD value of simulation room with traditional Kang heating system was 39.8%, while the average PPD value of simulation room with new heating system was only 13.47%. The simulation results show that the new integrated rural heating system has better indoor thermal comfortable, environmental benefits and social benefits than traditional Kang heating system, it is worthy of popularization and application.

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